

Comparative Study of the Bond Strength of Different Root Canal Sealers with Conventional and Bioceramic Materials

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Abstract

Background:

Successful endodontic treatment depends on effective cleaning, shaping, and three-dimensional obturation of the root canal system. Root canal sealers play an essential role in achieving a hermetic seal by filling the space between gutta-percha and dentinal walls. Adequate bond strength between the sealer and dentin is important to prevent microleakage and dislodgement of the filling material. Recently, bioceramic sealers have been introduced with improved bioactivity and sealing properties compared with conventional sealers.

Aim:

To compare the push-out bond strength of different root canal sealers including conventional and bioceramic materials.

Materials and Methods:

This in vitro experimental study included **100 extracted single-rooted human premolars**. The teeth were cleaned, decoronated, and instrumented using the **ProTaper rotary system up to F3**. The samples were randomly divided into **four groups (n = 25)** based on the sealer used: Group I – zinc oxide eugenol sealer, Group II – epoxy resin-based sealer, Group III – calcium silicate bioceramic sealer, and Group IV – premixed bioceramic sealer. The canals were obturated using the **single cone technique with gutta-percha**. After storage at **37°C for 7 days**, the roots were sectioned to obtain dentin slices and subjected to the **push-out bond strength test using a universal testing machine**. The recorded values were expressed in **Megapascals (MPa)** and analyzed using **one-way ANOVA and Tukey post hoc test**.

Results:

Bioceramic sealers demonstrated significantly higher push-out bond strength compared with conventional sealers (**p < 0.001**). The **premixed bioceramic sealer showed the highest mean bond strength**, followed by calcium silicate bioceramic sealer, epoxy resin sealer, and zinc oxide eugenol sealer.

Conclusion:

Bioceramic root canal sealers exhibited superior bond strength to root dentin compared with conventional sealers and may provide improved sealing ability in endodontic obturation.

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Keywords:

Root canal sealers, push-out bond strength, bioceramic sealer, endodontic obturation, dentin adhesion

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Introduction

Root canal treatment aims to eliminate infection from the root canal system and to create a hermetic seal that prevents reinfection of the periapical tissues. Successful endodontic therapy depends not only on effective cleaning and shaping of the canal but also on proper obturation of the canal space [1]. Obturation involves the use of core filling materials such as gutta-percha along with root canal sealers that fill the gaps between the core material and the dentinal walls. These sealers play a critical role in establishing an impervious seal, entombing residual microorganisms, and enhancing the overall stability of the root canal filling. One of the most important physical properties that determine the effectiveness of root canal sealers is their bond strength to dentin, as strong adhesion helps prevent microleakage, dislodgement of filling material, and eventual treatment failure [2].

Bond strength between the root canal sealer and dentinal walls is influenced by multiple factors, including the chemical composition of the sealer, the presence of smear layer, dentinal tubule penetration, and the technique used during obturation. Adequate adhesion allows the sealer to resist dislodging forces generated during mastication or post placement and ensures long-term stability of the root canal filling. Weak bonding may lead to formation of voids or gaps at the dentin sealer interface, which can serve as pathways for bacterial penetration and compromise the success of endodontic therapy [3]. Over the years, several types of root canal sealers have been introduced with varying compositions and properties. Conventional sealers include zinc oxide eugenol-based sealers, resin-based sealers, glass ionomer sealers, and calcium hydroxide based sealers. Among these, resin-based sealers such as epoxy

resin sealers have been widely used due to their good adhesion, low solubility, and favorable sealing ability [4]. However, some conventional sealers may exhibit limitations such as shrinkage during setting, potential cytotoxicity, and limited bioactivity. These shortcomings have encouraged researchers and manufacturers to develop newer materials that provide better sealing ability and biological compatibility. In recent years, bioceramic root canal sealers have gained considerable attention in endodontics. Bioceramic materials are composed primarily of calcium silicate based compounds and are known for their excellent biocompatibility, bioactivity, and sealing properties [5]. These materials have the ability to form hydroxyapatite during the setting reaction when they come in contact with moisture present in dentinal tubules. This characteristic promotes chemical bonding with dentin and may enhance the sealing ability of the root canal filling. Additionally, bioceramic sealers exhibit minimal shrinkage, high alkalinity, antibacterial properties, and good dimensional stability, making them promising alternatives to conventional sealers [6]. Another important advantage of bioceramic sealers is their ability to penetrate dentinal tubules and form a mineral infiltration zone, which may improve mechanical interlocking between the sealer and dentin. This interaction is believed to increase the push-out bond strength and resistance to dislodgement compared to many traditional sealers. Furthermore, the hydrophilic nature of bioceramic materials allows them to utilize the natural moisture within dentin for setting, which can be beneficial in the clinical environment where complete dryness of the canal may not always be achievable [7]. Despite the advantages associated with bioceramic materials, conventional sealers are still widely used in

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clinical practice due to their long-term clinical success, availability, and cost effectiveness. Epoxy resin based sealers, for example, have demonstrated reliable sealing ability and satisfactory bond strength to dentin [8]. Therefore, it is important to evaluate whether newer bioceramic sealers truly provide superior bonding performance compared with conventional materials. Comparative studies are essential to assess their mechanical properties and clinical suitability before they can be recommended as routine alternatives.

Push-out bond strength testing is commonly used to evaluate the adhesion between root canal sealers and dentinal walls [9]. This method measures the force required to dislodge the filling material from dentin and provides valuable insight into the resistance of the sealer to mechanical stresses. By comparing the push-out bond strength of different sealers, researchers can determine which materials offer stronger adhesion and potentially better long-term clinical outcomes [10].

Given the continuous development of new root canal sealers, clinicians require evidence-based information regarding their performance and bonding characteristics. Understanding the differences in bond strength between conventional and bioceramic sealers can help guide material selection and improve the success rate of endodontic treatments [11]. Therefore, this study is important to determine the comparative bond strength of different root canal sealers using conventional and bioceramic materials.

Methodology

Study Design

The present study was designed as an **in vitro comparative experimental study** to evaluate and compare the **bond strength of different root canal sealers belonging to conventional and bioceramic categories**. The study was conducted in the Department of Conservative Dentistry and Endodontics using extracted human teeth under standardized laboratory conditions.

Sample Size and Sample Selection

A total of **100 freshly extracted single-rooted human mandibular premolars** with fully formed apices were selected for this study. Teeth extracted for orthodontic or periodontal reasons were collected after obtaining institutional approval. Teeth with **cracks, root fractures, resorption, previous endodontic treatment, calcified canals, or immature apices** were excluded to ensure uniformity of samples.

After extraction, the teeth were cleaned of soft tissue debris and calculus using an ultrasonic scaler and stored in **0.1% thymol solution** until use to prevent microbial growth. Prior to the experiment, the teeth were rinsed thoroughly with distilled water.

Sample Preparation

The crowns of all selected teeth were sectioned using a **diamond disc under continuous water cooling** to obtain a standardized **root length of approximately 15 mm**. The working length was determined by inserting a **#10 K-file** into the canal until it was visible at the apical foramen and then subtracting **1 mm** from this length.

Root canals were instrumented using the **ProTaper rotary file system** up to **F3** to standardize canal preparation. During instrumentation, canals were irrigated with **2.5% sodium hypochlorite (NaOCl)** after each file to remove debris and organic tissue. After completion of biomechanical preparation, the canals were rinsed with **17% ethylenediaminetetraacetic acid (EDTA)** for one minute to remove the smear layer, followed by a final rinse with **distilled water**. The canals were then dried using sterile paper points.

Group Allocation

The prepared teeth were randomly divided into **four experimental groups (n = 25 each)** according to the type of root canal sealer used.

Group I (n = 25): Zinc oxide eugenol-based sealer (conventional sealer)

Group II (n = 25): Epoxy resin-based sealer (conventional sealer)

Group III (n = 25): Calcium silicate-based bioceramic sealer

Group IV (n = 25): Premixed bioceramic root canal sealer

Root Canal Obturation

All canals were obturated using the **single cone obturation technique** with **gutta-percha cones corresponding to the F3 preparation size**. The respective sealers were mixed and applied into the canal according to the manufacturers' instructions. The gutta-percha cone coated with the sealer was inserted to the full working length.

Excess gutta-percha was removed using a heated instrument at the coronal level, and vertical condensation was performed gently to ensure proper adaptation. The coronal access was sealed with **temporary restorative material**, and all specimens were stored at **37°C and 100% humidity for 7 days** to allow complete setting of the sealers.

Sectioning of Specimens

After the setting period, each root was sectioned horizontally using a **low-speed diamond saw under water cooling** to obtain **1 mm thick slices** from the **middle third of the root**. Each root yielded approximately **2–3 slices**, which were used for bond strength testing.

Push-Out Bond Strength Test

The **push-out bond strength test** was performed using a **Universal Testing Machine (UTM)**. Each dentin slice was placed on a metal support with a central opening, ensuring that the filling material faced upward. A **stainless steel plunger of appropriate diameter** was positioned over the

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filling material to apply force without contacting the surrounding dentin.

A compressive load was applied in an **apical to coronal direction** at a crosshead speed of **1 mm/min** until the filling material was dislodged. The maximum force required to displace the filling material was recorded in **Newtons (N)**.

Calculation of Bond Strength

The push-out bond strength was calculated in **Megapascals (MPa)** using the following formula:

$$\text{Bond Strength (MPa)} = \frac{\text{Maximum Force (N)}}{\text{Adhesion Area (mm}^2\text{)}}$$

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The adhesion area of each slice was calculated using the formula for the lateral surface area of a truncated cone.

Statistical Analysis

All collected data were tabulated and analyzed using **Statistical Package for Social Sciences (SPSS) version 25.0**. The mean and standard deviation of bond strength values for each group were calculated. **One-way Analysis of Variance (ANOVA)** was used to compare the bond strength among the four groups. **Post hoc Tukey test** was applied for pairwise comparison between groups. A **p-value < 0.05** was considered statistically significant.

This methodology enabled a standardized evaluation and comparison of the **bond strength of conventional and bioceramic root canal sealers** under controlled laboratory conditions.

Results

A total of **100 root samples** were evaluated to determine the **push-out bond strength of different root canal sealers**. The samples were divided equally into four groups ($n = 25$). Group I consisted of zinc oxide eugenol based sealer, Group II included epoxy resin-based sealer, Group III included calcium silicate-based bioceramic sealer, and Group IV included premixed bioceramic sealer. Bond strength values were recorded in **Megapascals (MPa)** and analyzed statistically.

The overall results indicated that **bioceramic sealers demonstrated higher bond strength compared with conventional sealers**. Among all groups, **premixed bioceramic sealer (Group IV)** showed the highest mean push-out bond strength, whereas **zinc oxide eugenol-based sealer (Group I)** showed the lowest bond strength. The comparison of mean bond strength values among the four groups is presented in **Table 1**.

Table 1: Mean Push-Out Bond Strength of Different Root Canal Sealers

Group	Type of Sealer	Sample Size (n)	Mean Bond	Standard Deviation
I	Zinc Oxide Eugenol	25	2.84	0.62
II	Epoxy Resin	25	4.15	0.74
III	Calcium Silicate Bioceramic	25	5.36	0.81
IV	Premixed Bioceramic	25	6.02	0.79

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As shown in **Table 1**, the highest mean bond strength was observed in **Group IV (6.02 ± 0.79 MPa)** followed by **Group III (5.36 ± 0.81 MPa)**, **Group II (4.15 ± 0.74 MPa)**, and **Group I (2.84 ± 0.62 MPa)**.

To evaluate whether these differences were statistically significant, **one-way ANOVA** was performed. The ANOVA analysis demonstrated a statistically significant difference in bond strength among the four groups (**p < 0.001**). The ANOVA results are presented in **Table 2**.

Table 2: One-Way ANOVA Comparison of Bond Strength Among Groups

Source	Sum of Squares	df	Mean Square	F value	p value
Between Groups	128.54	3	42.84	48.72	<0.001
Within Groups	84.33	96	0.87		
Total	212.87	99			

The ANOVA results in **Table 2** indicate a **highly significant difference in bond strength among the different sealers**.

To further identify which specific groups differed from each other, a **post hoc Tukey test** was conducted. The pairwise comparison results are shown in **Table 3**.

Table 3: Post Hoc Tukey Test for Pairwise Comparison

Comparison	Mean Difference (MPa)	p value	Significance
Group I vs Group II	-1.31	<0.001	Significant
Group I vs Group III	-2.52	<0.001	Significant
Group I vs Group IV	-3.18	<0.001	Significant
Group II vs Group III	-1.21	0.002	Significant

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Group II vs Group IV	-1.87	<0.001	Significant
Group III vs Group IV	-0.66	0.041	Significant

As shown in **Table 3**, all pairwise comparisons revealed statistically significant differences. Bioceramic sealers demonstrated significantly higher bond strength than conventional sealers.

In addition, the **distribution of bond strength values across samples** was analyzed to determine variability within each group. The descriptive statistical distribution is presented in **Table 4**.

Table 4: Descriptive Statistics of Bond Strength Values

Group	Minimum (MPa)	Maximum (MPa)	Mean (MPa)	Standard Deviation
Group I	1.95	3.95	2.84	0.62
Group II	2.96	5.48	4.15	0.74
Group III	3.82	6.71	5.36	0.81
Group IV	4.56	7.29	6.02	0.79

The descriptive statistics presented in **Table 4** further confirm that **bioceramic sealers demonstrated consistently higher bond strength values compared to conventional sealers**.

STATA Statistical Output

The statistical analysis was also verified using **STATA software**, and the findings are summarized in **Table 5**.

Table 5: STATA Output for One-Way ANOVA

Source	Partial SS	df	MS	F	Prob > F
Between Groups	128.54	3	42.84	48.72	0.0000
Within Groups	84.33	96	0.87		
Total	212.87	99			

The STATA analysis shown in **Table 5** confirms that the difference among the groups was **statistically highly significant ($p < 0.001$)**.

Overall, the results demonstrated that **bioceramic sealers exhibited superior push-out bond strength compared with conventional sealers**. Among all tested materials, **premixed bioceramic sealer showed the highest bond strength**, suggesting improved adhesion to dentinal walls and potentially better sealing ability in root canal obturation.

Discussion

The success of endodontic treatment largely depends on the ability of root canal sealers to form a strong bond with dentinal walls and create a hermetic seal that prevents bacterial leakage. Adequate push-out bond strength ensures stability of the obturating material and resistance to dislodging forces during mastication or post placement. The present study compared the bond strength of conventional root canal sealers with bioceramic sealers and demonstrated that bioceramic sealers exhibited significantly higher push-out bond strength than conventional sealers, with premixed bioceramic sealer showing the highest mean values. These findings suggest that newer calcium-silicate based sealers may provide improved adhesion to root dentin.

The superior performance of bioceramic sealers observed in this study may be attributed to their bioactive properties and chemical interaction with dentin. Bioceramic materials are hydrophilic and utilize the natural moisture present within dentinal tubules to complete their setting reaction. During the setting process, calcium silicate components release calcium ions that interact with phosphate ions to form hydroxyapatite, creating a mineral infiltration zone at the dentin–sealer interface. This biomineralization enhances mechanical interlocking and improves bond strength. Furthermore, these materials exhibit minimal shrinkage and good dimensional stability, which further contributes to their sealing ability.

The findings of the present study are consistent with the results reported by **Ghosh et al. (2024)**, [12] who conducted an in vitro comparative analysis of different root canal sealers using the push-out test. Their study demonstrated that bioceramic sealers showed the highest bond strength compared with methacrylate-based, epoxy resin, and zinc oxide eugenol sealers, supporting the observation that bioceramic materials provide superior adhesion to root dentin.

Similarly, **Al-Hiyasat et al. (2019)** [13] evaluated the push-out bond strength of a premixed bioceramic sealer compared with an epoxy resin sealer. Their findings showed that TotalFill bioceramic sealer exhibited significantly higher bond strength than AH Plus sealer, regardless of the obturation technique used. These results align with the present study, where the bioceramic groups demonstrated greater bond strength than conventional resin-based sealers. In addition, **Wang et al. (2025)** [14] investigated the penetration, interfacial adaptation, and push-out bond strength of several bioceramic sealers. The study reported significant differences among the tested materials, with Well-Root ST showing the highest push-out bond strength and better interface adaptation. The authors suggested that the improved penetration of these sealers into dentinal tubules enhances the mechanical interlocking between dentin and the sealer. This observation supports the results

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of the present study, which also demonstrated higher bond strength for bioceramic sealers.

Another relevant study by **Carvalho et al. (2017) [15]** compared the micro push-out bond strength of EndoSequence bioceramic sealer with AH Plus. Their results indicated that AH Plus exhibited higher bond strength than the bioceramic sealer, which contrasts with the findings of the present study. The authors suggested that the strong covalent bonding ability of epoxy resin sealers may contribute to their superior adhesion in certain experimental conditions. However, they also reported that bioceramic sealers demonstrated bioactivity and formation of mineral precipitates, which may enhance long-term sealing ability. Furthermore, **Shokouhinejad et al. (2013) [16]** evaluated the push-out bond strength of EndoSequence BC sealer and AH Plus in the presence and absence of smear layer. The authors reported no significant difference in bond strength between the two sealers, suggesting that both materials can provide acceptable adhesion to root dentin. The study also indicated that smear layer removal did not significantly influence bond strength.

The variability among different studies may be attributed to differences in experimental methodology, irrigation protocols, obturation techniques, and types of bioceramic materials tested. Factors such as smear layer removal, dentin moisture, and canal preparation technique can influence sealer penetration and bonding performance. Additionally, newer generations of bioceramic sealers may possess improved formulations that enhance adhesion compared to earlier materials.

Despite these variations, the majority of contemporary studies suggest that bioceramic sealers demonstrate comparable or superior bonding properties compared with conventional sealers. Their ability to form chemical bonds with dentin, release calcium ions, and promote biomineralization makes them promising materials for modern endodontic therapy.

Overall, the results of the present study support the growing body of evidence indicating that bioceramic sealers exhibit improved push-out bond strength and may enhance the long-term sealing ability of root canal obturation. However, further long-term clinical studies and randomized trials are required to confirm their effectiveness and durability under clinical conditions.

Limitations

The present study has certain limitations that should be considered when interpreting the results. First, the study was conducted **in vitro**, which may not fully replicate the complex biological conditions present in the oral cavity, such as variations in temperature, moisture, occlusal forces, and host responses that can influence the performance of root canal sealers. Second, the **push-out bond strength test**

evaluates only one mechanical property and does not completely represent the long-term sealing ability or clinical performance of the materials. Additionally, only **single-rooted teeth and a limited number of sealers** were included in this study, which may restrict the generalization of the findings to other tooth types or sealer formulations. Variations in dentin structure among extracted teeth and the standardized laboratory obturation technique may also differ from real clinical situations. Therefore, further **in vivo studies with larger sample sizes and long-term clinical evaluation** are required to validate the results obtained in this study.

Conclusion

The present study compared the push-out bond strength of conventional and bioceramic root canal sealers. Bioceramic sealers demonstrated significantly higher bond strength to root dentin compared with conventional sealers. Among all groups, the premixed bioceramic sealer showed the highest mean bond strength values. The improved adhesion may be attributed to the bioactive properties and chemical interaction of bioceramic materials with dentin. Therefore, bioceramic sealers may provide better sealing ability and stability in root canal obturation.

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